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ORIGINAL ARTICLE

Area traffic capacity in centeral areas – Alexandria city center as a case study

Aly Hassan, Mohamed Maher Shahin *, Mahmoud Morsy

Transportation Department, Faculty of Engineering, Alexandria University, Egypt

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Traffic management;
Travel demand management

Abstract In many cities, worldwide, city centers are highly congested. The reason is that the Area Traffic Capacity (ATC) becomes constrained; i.e. the traffic and parking demands (mainly motorized), continually, increase within a finite roads' and car parks' capacity. The central Area Traffic Capacity (ATC) could be either the capacity of the internal road network, the parking capacity, or the capacity of the approach roads leading into the area. One of these three elements limits the overall traffic capacity. Therefore, the main objective of this paper is to develop a planning process which can be used as a tool for determining the ATC, and producing and evaluating different solutions (or scenarios) that can improve a central area traffic capacity. The proposed planning process is based on a combined analysis of traffic and parking situations which result from the travel demand and the traffic supply in a city center. If the travel demand is greater than the area traffic capacity, the process reflects feedback effects of parking and traffic situations on the desired supply or demand. Thus, it can be used to analyze different possible improving strategies, which might be needed to achieve favorable situations (formulating scenarios). The proposed planning process is then applied to estimate the area traffic capacity of Alexandria city center and to analyze the impacts of applying some traffic strategies in order to improve the ATC.

* Corresponding author. Mobile: +20 01002591180.
E-mail address: mohamedsaz@hotmail.com (M.M. Shahin).

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1. Introduction

A city center of a metropolitan area is the heart of the city where urban functions are intensively concentrated [1]; i.e. the social, cultural, business and entertainment activities. It is the economic engine of an urban area, and it suffers from even worse congestion conditions than the rest of the city [2]. Traffic congestion in central areas is one of the significant problems in many cities worldwide, due to the rapid economic and demographic growths within a finite area traffic capacity [3]. Too much traffic on a given traffic infrastructure negatively influences the city center urban image and functions, causing traffic congestion, noise, pollution, frequent accidents, safety risk and stressed nerves. Consequently, the quality of urban life in central areas is starting to deteriorate. Actually, the city center has become hostile, and its urbanity is in danger. In order to develop strategies to alleviate city center congestion, it is necessary to identify the Area Traffic Capacity (ATC) then it could develop suitable strategies to increase this capacity. Area Traffic Capacity (ATC) for a central area is an expression that can be defined as the maximum number of vehicles that can, at a given time, move or park in that area. It could be either the capacity of the internal road network, or the parking capacity, or the capacity of the approach roads leading into the area i.e. the one which produces a lower level of service in the central area than the others. For relieving the current ATC two approaches can be applied:

1. Traffic management strategies can submit modern technologies to match traffic flow with traffic infrastructure; such as co-ordinated traffic signals, car park guidance systems, congestion pricing, and automated enforcement systems. These activities are useful for increase area roads capacity to improve an area traffic capacity.
2. Travel Demand Management hypotheses (TDM) can be used to reduce travel demand to fit the actual available area traffic capacity. TDM hypotheses seek to modify travel behavior and mode choice decisions so as to reduce the negative impacts of car use. There are numerous TDM hypotheses; such as parking restriction, public transportation developments, congestion pricing, introducing park and ride facilities, land use policies, as well as setting alternative work schedules and carpooling.

In order to achieve maximum benefits, a set of scenarios of traffic management strategies and travel demand management hypotheses must be formulated and evaluated to achieve the best scenario which achieves the maximum ATC. In this paper, a planning process for determining central area traffic capacity is proposed. It can also be applied to assess the impacts of traffic and travel management strategies on traffic demand and traffic supply. One of the most important emphases here is the prediction of the service level of the traffic system which encourages the usage of public transport, and at the same time prevents losses of the city center activities that can be the result of traffic jams and parking shortages. The planning process is then tested and applied to estimate the traffic capacity of Alexandria central area.

2. Area traffic capacity

2.1. Definition

Area Traffic Capacity (ATC) can be defined as the maximum number of vehicle trips which have their destinations in a given area or cross that area in a certain time interval. This means, the maximum number of vehicles that can, at a given time, move or park in the area. It should be clearly stated what is understood by "maximum number". It is not the absolute "maximum number" corresponding to full saturation of roads and car parks, but the practical "maximum" which satisfies a pre-specified level of service. The central area traffic capacity could be either the capacity of the internal road network, the parking capacity, or the capacity of the approach roads leading into the area (Fig. 1). One of these three elements limits the overall traffic capacity, i.e. the one which produces a lower level of service in the central area than the others [4]. In the framework of this idea, a procedure for determining the traffic capacity for central areas is developed. The procedure is based on a combined analysis of traffic and parking situations which result from expected traffic demand and projected traffic supply in a city center. The traffic and parking situations (supply/demand ratios) define the overall central Area Traffic Capacity (ATC). This means that the area traffic capacity can be determined by multiplying the lowest value of the different supply/demand ratios by the actual unrestrained internal traffic volumes.

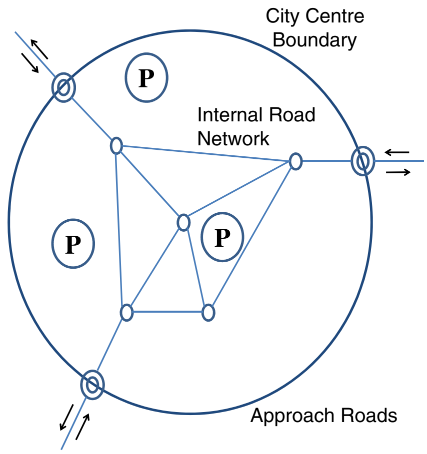

Figure 1 Area traffic capacity elements.

2.2. Impacts of traffic management and travel management on ATC

The main objectives of this paper are to present a procedure for determining Area Traffic Capacity (ATC) and developing possible strategies for alleviating current capacity restriction where the demand is higher than the area traffic capacity. In such case, the lowest of parking situation, internal road network situation and approach roads situation are controlling the area capacity. Therefore, in order to improve the area's situation; the lowest situation should be improved by increasing the capacity using traffic management strategies, decreasing the demand using travel demand management hypotheses or using the two approaches in order to conduct an effective solution (Fig. 2). Generally, the proposed strategies mentioned above, may be an effective tool in order to relieve the existing ATC, but the individual application of any of them may achieve a limited improvement for ATC. Thus, in order to achieve maximum benefits, a set of scenarios of traffic management strategies and travel demand management hypotheses will be formulated and evaluated to realize the best scenario which achieves the maximum ATC.

2.2.1. Proposed traffic management strategy

Modern traffic management systems can submit modern technologies to meet the challenges of increasing travel demand on a limited traffic (to match traffic flow with traffic infrastructure); such as co-ordinated traffic signals, car park guidance systems, congestion pricing, and automated enforcement

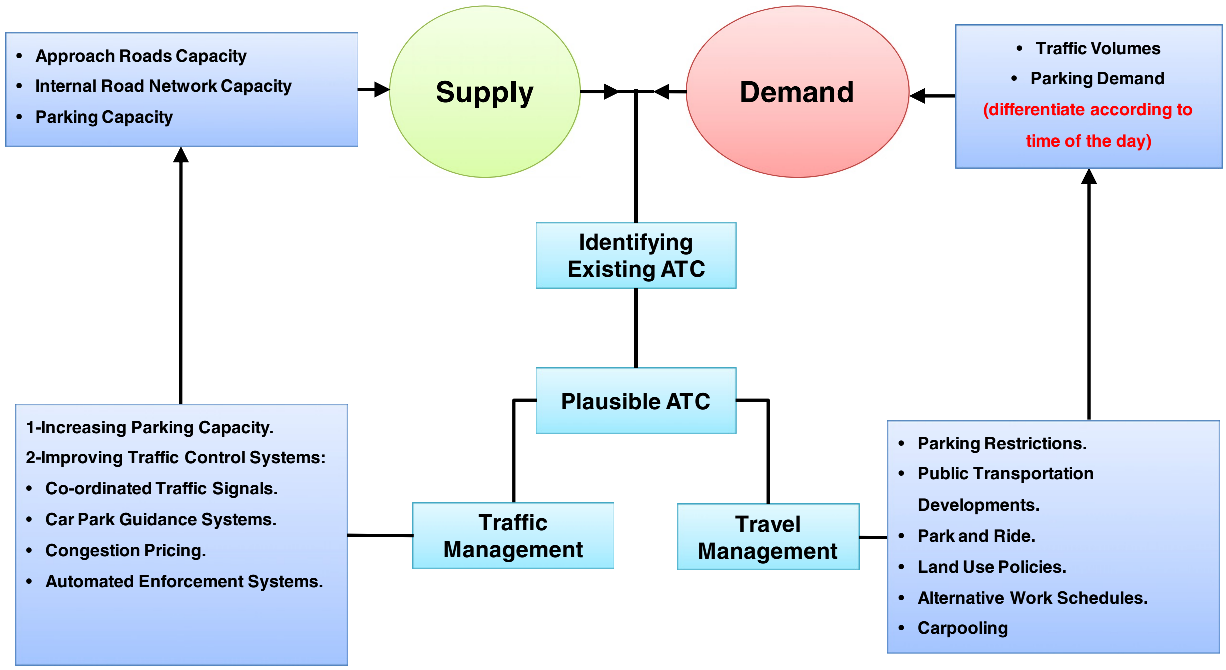

Figure 2 Improving the existing ATC.

systems. These activities are useful for maximizing an area traffic capacity. In this paper a co-ordinated traffic signals system is proposed to apply as a traffic management strategy. A co-ordinated traffic signals system may achieve the following benefits:

· Optimizing traffic flows, minimizing congestion and reducing traffic delays.
· Improving safety.
· Enhancing the environment by reducing fuel consumption and emissions.

2.2.2. Proposed travel demand management hypotheses

Travel Demand Management hypotheses (TDM) can be used to reduce travel demand to fit the actual available area traffic capacity. TDM hypotheses also seek to modify travel behavior and mode choice decisions so as to reduce the negative impacts of car use. There are numerous TDM hypotheses representing the complexity of the urban environment and transportation issues such as long-term parking restriction, public transportation improvements, congestion pricing, introducing park and ride facilities, land use policies, as well as setting alternative work schedules and carpooling. By optimizing the use of the existing road network, TDM hypotheses can also defer or remove the need for expensive new capacity improvement projects.

2.2.2.1. Long term parking restriction hypothesis. It is assumed here that traveling by car is so attractive and comfortable regardless of the relative costs and travel times, only the parking and traffic situations in the central area will limit the usage of car. Modal choice for work trips should be primarily affected. Parking duration restrictions (1–2 h, for example) provide priority for short-term parking. This means that the parking spaces of the central area will be filled first by the central area residents, then by visitors and the remaining spaces, if any, will be available for work trips. Reserving some parking spaces for visitors raises the attractiveness of the service activities in the central area [12]. In addition, traffic limitation can successfully be used to perform a balanced traffic system in the city center. Both roads and car parks should be saturated to the same extent [13]. If the parking capacity is less than the road network capacity, traffic limitation measures such as pedestrian zones and bus lanes passively affect the service level of the network roads. In this case, some employees may give up car trips and perhaps use public transport which should produce better level of service.

2.2.2.2. Public transportation improvement hypothesis. This hypothesis is based on the assumption that the relative level of service offered by public and private transport is the critical factor in affecting modal choice. The level of service (under this hypothesis) is influenced by the comparative travel times, i.e. private to public transport travel time ratio. This travel time ratio can be expressed as the time ratio of door-to-door travel time by private transport divided by the door-to-door travel time by public transport. Changes in modal choice can be realized by improving the service level of the public transport system (for example: increasing comfort, running speed, frequencies, and reducing transfer time). The degree of improving the service level of public transport depends on the rate of using private transport that guarantees proper parking and traffic situations in the city center. Under this hypothesis, there is no restriction on parking duration. Parking spaces are operated on first-come, first-served base [14], assuming that it is unfeasible to manage strict parking durations.

2.2.2.3. Integration of parking restriction and public transportation improvements. It includes the assumptions embodied in both hypotheses previously described; i.e. realizing parking and traffic restrictions, and at the same time improving public transport service. These measures can simultaneously be applied to conduct an effective solution in case of dramatic traffic situations, particularly under the following circumstances:

- Drastic traffic and parking restriction measures are very difficult to be realized and controlled.
- Chances for improving the projected public transport system are limited.

3. ATC planning process

The planning process is established on the basis of three approaches: collecting data, developing current Area Traffic Capacity (ATC) and developing maximum ATC using one or more of traffic and travel management strategies such as coordinated traffic signals, long-term parking restriction measurements, public transportation developments and integration of long-term parking restrictions and public transportation developments. The required data is used to identify the current traffic and parking demand for a city center area, as a whole, as well as identifying the current approach roads capacity, internal road network capacity and parking capacity for a city center area as a whole. Identifying the current traffic and parking demand for a city center area as whole requires information at macrolevel relating to urban mobility data within the city center area as a whole. These types of data may be classified into, travel behavior data and socio-economic data. The data sources include transportation surveys, census of population, household interview, local and national authorities. The analysis of the urban mobility data provides current peak hour traffic volumes on city center road network as a whole for different trip purpose of different modes as well as the maximum area parking demand for different trip purpose.

Identifying the current approach roads capacity and internal road network capacity for a city center area as a whole requires information at microlevel relating to urban structure data. These types of data require traffic surveys which establish the database for micro-simulation model which use to estimate the current roads capacity with the help of commercial traffic simulation Software; e.g. VISSIM. A micro-simulation model data base involve network data, traffic volume data, public transportation data, vehicle and driver performance characteristics data, speed data, signal control data and calibration data.

The analysis of the demand and the supply data provides calculation of the current ATC. The current ATC is considering the minimum value which may needs to maximize in order to reduce the current traffic and parking problems. Once the present ATC has been determined, the relationship between ATC and the actual existing demand explains the current city center situation which attempts to identify city center problems that require treatment (e.g. limited parking situation, limited traffic infrastructure or limited parking and traffic infrastructure). Thus, In order to achieve the maximum benefits from the proposed strategies, a set of scenarios of traffic management strategies and travel demand management hypotheses should be formulated and evaluated to gain the best scenario which achieves the better utilization for the ATC within a certain area.

Fig. 3 presents a developed procedure for determining the traffic capacity for central areas. The procedure is based on a combined analysis of traffic and parking situations which result from expected traffic demand and projected traffic supply in a city center. The traffic and parking situations (supply/demand ratios) define the overall central Area Traffic Capacity (ATC). This means that the area traffic capacity can be determined by multiplying the lowest value of the different supply/demand ratios by the actual unrestrained internal traffic volumes.

The proposed procedure is a six step modal which can be carried out iteratively according to the consequences of the following relationships:

3.1. Step 1: Peak-hour traffic volumes on internal road network

The traffic volumes on internal road network could be estimating from the city O/D trip matrix and model split. Thus, the peak hour traffic volumes on internal network (V) could be determined as follows:

$$V = V_i + V_e + V_t \tag{1}$$

where V_e is the external/internal + internal/external traffic volumes during peak hour; V_t the through traffic volumes during peak hour; and V_i is the internal traffic volumes during peak hour.

3.2. Step 2: Peak-hour traffic volumes on approach roads leading into an area

The traffic volumes on approach (external) roads, the peak hour traffic volumes on approach roads (V_a) could be determined;

$$V_a = \sum_{i}^{n} \mathrm{QI}_i + \mathrm{QO}_i$$

where V_a is the total peak-hour volumes on all approach roads intersecting the city center cordon line (pcu/h); QI_i the peak hour traffic volumes entering the city center at the approach road i (pcu/h); QO_i the peak hour traffic volumes leaving the city center at the approach road i (pcu/h); and n is the number of the approach roads (i = 1, ... , n).

Also, the traffic volumes on approach roads can be determined using the following relation:

$$V_a = 2V_t + V_e \tag{2}$$

3.3. Step 3: internal road network and approach roads capacity

The term capacity when referring to a road network is its ability to carry, accommodate or handle traffic flow. The basic capacity for a certain road can be defined as the maximum volume of vehicles per hour that can pass a certain point or section of a road in a given time under the ideal condition (ideal traffic flow speed, most ideal road way and control conditions that can possibly be attained). Micro-simulation model selection is a very broad topic and is only dealt here very broadly with regard to capacity and breakdown observations. The model selected should have the necessary stochastic elements and the capability to simulate breakdown as a random event. Stochastic elements include the vehicle and driver capabilities. Specifically, the acceleration and deceleration parameters for each vehicle, including

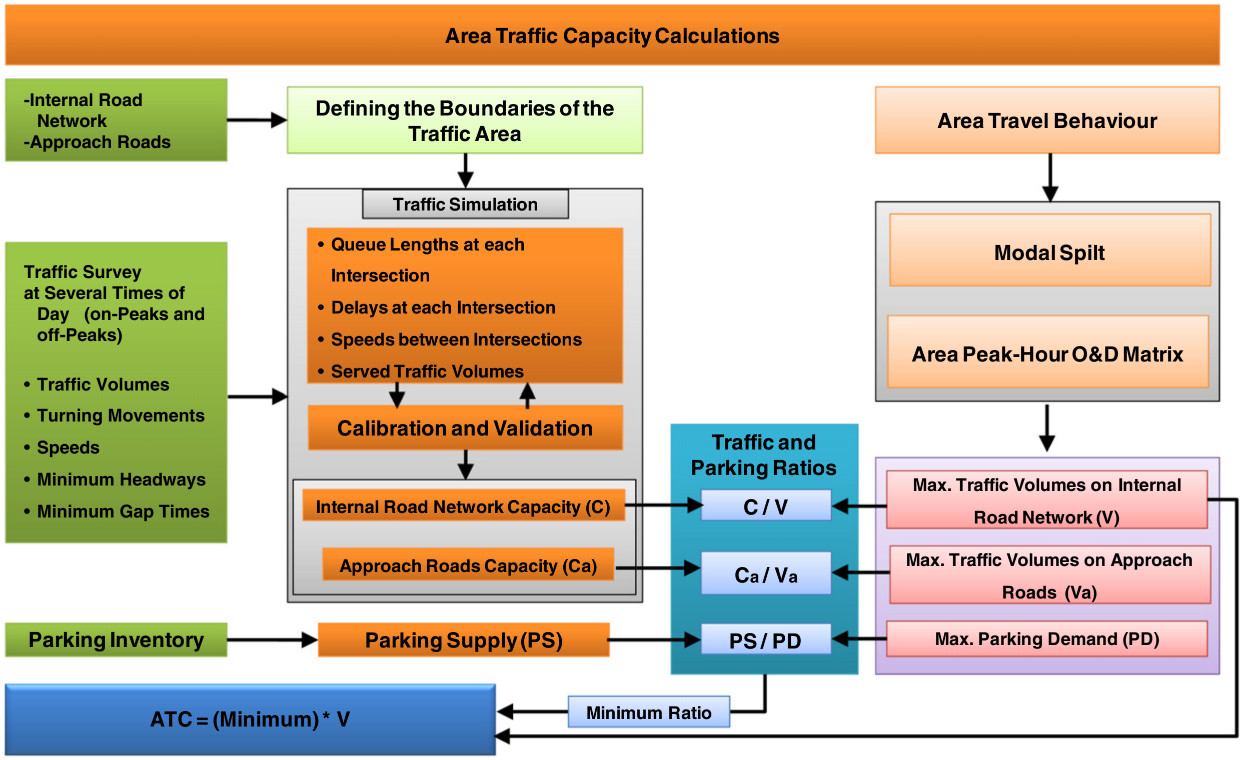

Figure 3 Area traffic capacity calculations.

the car-following models, should address and be calibrated for breakdown conditions. Similarly, the lane-changing algorithm of the model selected should consider and be calibrated for breakdown conditions [7].

The second consideration when using simulation modeling for capacity estimation is what demands to use and how to vary them so that breakdown is achieved. The most common technique is to run the model with incrementally higher demands, starting at a sufficiently low, below-capacity level. The analyst would need to load the network starting with relatively low demands and increasing them at constant intervals until breakdown is reached. Another, more complicated, technique is to develop random patterns of demand to simulate the demand patterns in the field. For both techniques the increments employed at each successive demand level would be a function of the desired interval in the capacity observations. Output data can then be collected on breakdown events and maximum throughput, similarly to the field data collection. Examples of traffic micro-simulation models include SimTraffic, CORSIM, VISSIM and AIMSUN.

From above, the capacity of an area approach roads or the whole area internal road network can be estimated by developing a calibrated traffic micro-simulation model for the area road network, such model could represent the field measured and observed traffic conditions (speed) in order to determine the area roads capacity.

3.4. Step 4: Parking demand

Parking demand depends on trip generation, trip purpose and land use [5]. Parking demands are not generated by the building space itself, but it is generated by the number of residents in the area, attractive travelers' purpose and its mode of transportation [6]. In a comprehensive study, the parking demand is estimated with the use of mathematical model, which includes the effect of residents' demand, work trips as well as other purposes trips demand where;

$$\begin{aligned} \mathrm{PD} &= \mathrm{PD}_r + \mathrm{PD}_w + \mathrm{PD}_o \\ &= (0.001 \times \mathrm{COW}_r \times R \times m_r) + (\mathrm{DVT}_{c,w} \times m_w) \\ &\quad + (\mathrm{DVT}_{c,o} \times m_o) \end{aligned} \tag{3}$$

where PD is the maximum parking demand; PD_r the parking demand of residents; PD_w and PD_o the parking demand during peak period of work and other purpose trips, respectively; COW_r the car ownership of the city center residents; R the number of residents (population); m_r, m_w, m_o the parking demand coefficients of the peak period for residents as well as for work and other purpose trips, respectively; $\mathrm{DVT}_{c,w}$ the daily traffic volume by car for work trips; $\mathrm{DVT}_{c,o}$ the daily traffic volume by car for other purpose trips; and $\mathrm{DVT}_{c,w}$ and $\mathrm{DVT}_{c,o}$ can be calculated by the following relation.

The daily person trips terminating in the city center by mode m for trip purpose p can be estimated as follows:

$$\mathrm{DVT}_{m,p} = \mathrm{DPT}_{m,p} \times S_{m,p}/\mathrm{OC}_m \tag{4}$$

The peak hour parking coefficients can be estimated by a parking survey process in order to collect data about the observed vehicles in a certain time for each parking purpose (residents, work or other). This type of data may be collected by applying a vehicle plate registration process as a parking survey method.

3.5. Step 5: Parking capacity

Parking capacity or parking supply (PS) is the number of provided parking places. Small city can provide predominantly off-street parking places meanwhile large city and central areas can provide predominant parking lot or parking garage [6]. The parking supply for any area can be estimated by surveying the available parking places within this area along with the parking control conditions for each set of parking places.

3.6. Step 6: Determination of ATC

The traffic and parking situations (supply/demand ratios) define the overall Area Traffic Capacity (ATC). This means that the area traffic capacity can be determined by multiplying the lowest value of the different Supply /Demand ratios by the actual unrestrained internal traffic volumes where;

$$\mathrm{ATC} = (\mathrm{supply/demand\ ratio})\min * V \tag{5}$$

In a city center, if the area capacity is equal or higher than the demand, the traffic and parking situations have a good effect on the level of service for the area roads In case of higher demands, some traffic and transport strategies are essentially needed to prevent severe traffic and parking congestions in the city center. The demands should be adapted with the traffic capacity.

4. ATC improvement policies

4.1. Introduction of coordinated traffic signals

There are three terms used when discussing traffic signal coordination, (1) phase, a predetermined set of traffic signal movements that operate concurrently, (2) cycle time, the total time taken to run once through all phases for an intersection, (3) offset, for coordinated traffic signals the beginning or end of the green period on the coordinated approach of each intersection is set to occur a given time relative to that at the reference intersection. This time is known as the offset [9]. Therefore, coordination is achieved through three features:

(1) Traffic signals run on a common cycle time (or in special cases, one half of the cycle time).
(2) The beginning or end of the green period on the coordinated approach of each intersection is set to occur at the offset time relative to that at the reference intersection. This offset is determined by the distance between the signals, the progression speed along the road, and the queues of vehicles waiting at red signals.
(3) The optimization of offsets and phase times.

In past years, traffic engineers developed these diagrams by hand, optimizing them by hand or through the use of simple computer programs. Today, however, most traffic engineers use complex computer programs and simulations to develop signal timings, though most still visualize those timings using time–space diagrams. Such process may be achieved by the help of a calibrated micro-simulation model (e.g. VISSIM) which can represent the co-ordinated signals system and evaluate various offset and phase times until gain the best outputs such as minimum delays, minimum queue lengths, minimum travel times as well as maximum capacity.

4.2. Long term parking restriction hypothesis

The effect of applying the long term parking restriction (work trips parking restriction) on the modal spilt may be concluding by calculating the optimum car share and its effect on other modes share. The optimum car share should be suitable with the available supply and the required travel demand according to the city center three elements, internal network, approach network and parking. (Fig. 4a) presents the relationships between car share and travel time ratios (private to public transport) under the parking restriction hypothesis.

In this paper a formula for determining the required car share under work trips parking restriction was adapted and investigated. Under this alternative, parking restrictions limit the private car share of work trips to the city center. The net capacity available for work trips (DV_w) has to determine by subtracting the demand created by other traffic from the total capacity. Then, the desired car share of work trips ($\mathrm{DS}_{c,w}$) can be obtained from:

$$\mathrm{DS}_{c,w} = \frac{(\mathrm{DV}_w/f_w) - Y}{(X - Y)} \tag{6}$$

where DV_w is the desired traffic volume for work trips only and f_w is the peak hour work trips.

$$X = \frac{1}{\mathrm{OC}_c}$$

$$Y = \sum \frac{R_m * \mathrm{PCUF}_m}{\mathrm{OC}_m}, \quad R_m = \frac{S_m}{\sum S_m}$$

$\sum S_m =$ summation of all modes share without private car share

where PCUf_m is the passenger car unit factor for mode m; S_m the share ratio for mode m for all trip purposes; OC_m the occupancy of mode m.

The desired car share of all trips (DS_c) can be obtained from:

$$\mathrm{DS}_c = \frac{f_w * \mathrm{DS}_{c,w} + f_o * S_{c,o}}{f} \tag{7}$$

where f_o is the peak hour trips for other trip purposes (all trips – work trips) and f is the peak hour trips for all trip purposes.

4.3. Public transportation improvement hypothesis

Under this policy, there is no restriction on parking duration. Parking spaces are operated on first come, first served base, assuming that it is unfeasible to manage strict parking durations. Fig. 4b presents the relationships between car share and travel time ratios (private to public transport) under the public transportation improvement hypothesis.

Under this alternative, improvement of public transport service (bus modes) is needed to reduce the usage of private cars. Hence, a shift would occur from private car modes (C) to bus modes (B). To perform an appropriate traffic situation in the city center, the desired car share of all trips (DS_c) should be equal to:

$$\mathrm{DS}_c = \frac{(\mathrm{DV}/f) - Z(S_B + S_C) - Y^{\backslash}}{X - Z} \tag{8}$$

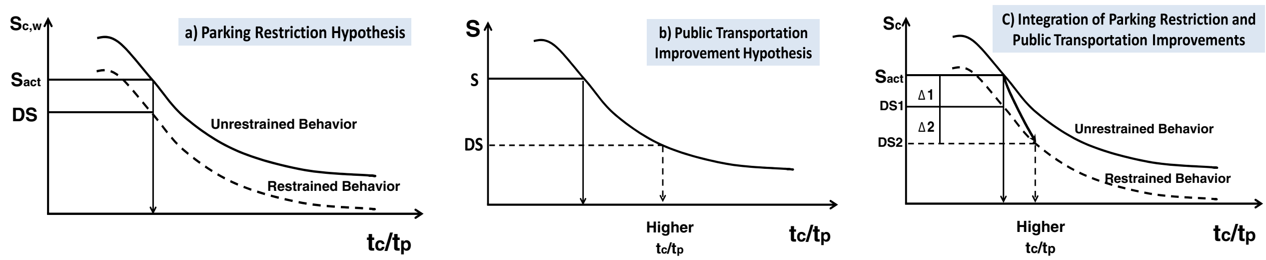

Figure 4 Relationship between car share and travel time under different hypothesis.

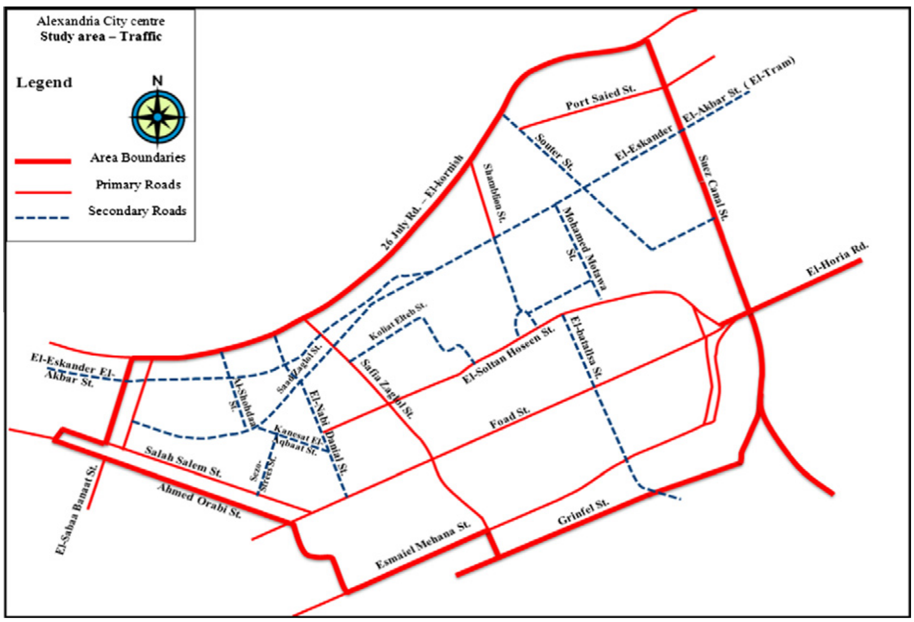

Figure 5 Alexandria central area and the existing traffic facilities.

Table 1 Trips distribution according to mode of transportation in normal days.

Mode of transportation	All trip purposes	Work trip purpose
Bus	6.4	8.0
Mini-bus	6.0	8.0
Tram El-Raml	5.8	8.0
Tram El-Madina	4.9	2.0
Private bus	4.0	3.0
Collective taxi	28.3	32.25
Taxi	26.7	12.0
Private car	17.9	26.75
Total	100.0	100.0

where DV is the desired traffic volume for all trip purposes and f is the peak hour trips for all trip purposes.

$$X = \frac{1}{\mathrm{OC}_c}$$

$$Y' = \sum \frac{S_m * \mathrm{PCUF}_m}{\mathrm{OC}_m} \text{(does not include car and bus modes)}$$

$$Z = \left[\frac{\mathrm{PCUF}_B}{\mathrm{OC}_R}\right]$$

4.4. Integration of parking restriction and public transportation improvements

Fig. 4c presents the relationships between car share and travel time ratios (private to public transport) under the public transportation improvement hypothesis.

The integration process depends on the ability of the implementation process for the parking restrictions, as well as the limitations of developing the public transportation facilities. The ability of implementing parking restrictions may be identified by investigating the local authority about the ability of such policies to be realized and controlled. Also, applying a stated preferences survey in the city center area is very important measure in order to collect data about the receptivity of the community for such restrictions on their own travels. The limitations of developing the public transportation facilities are required for social and economical studies in order to determine the extent of the new services that can be compatible with the social income. Moreover, applying a stated preferences survey for public transportation is so important in

Table 2 VISSIM calibration parameters (default and calibrated values).

No.	Parameters	VISSIM default values	VISSIM calibration values
1	No. of observed vehicles (veh.)	4	4
2	Average stand still distance (m)	2	1.20
3	Additive part of desired safety distance	3	2
4	Look ahead distance (min, max) (m)	(0, 250)	(20, 200)
5	Look back distance (min, max) (m)	(0, 150)	(20, 150)
6	Maximum deceleration (own, trailing vehicle) (m/s^2)	(−4, −3)	(−4.6, −4.6)
7	Waiting time before diffusion (s)	60	30
8	Minimum headway (front/rear) (m)	0.50	0.40
9	Maximum deceleration for cooperative braking (m/s^2)	−3	−4.6

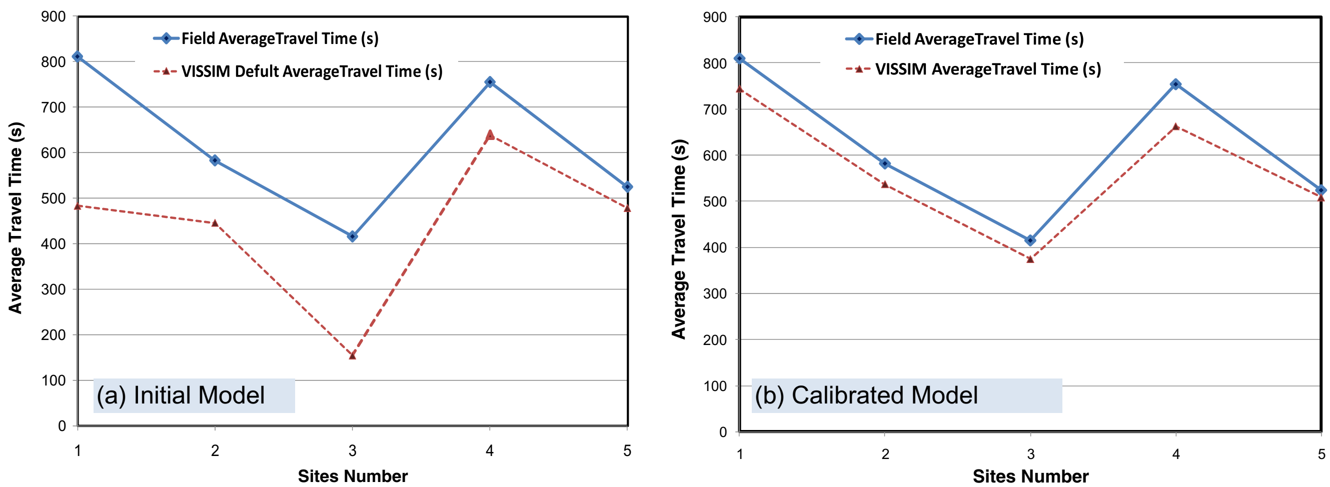

Figure 6 Example for field versus VISSIM measurements.

Table 3 Existing traffic and parking situations.

Element	Car share (S_c)	Supply	Demand	Supply/demand	ATC (pcu/h)
Internal roads	17.9%	29,348	30,481	0.96	25,500
Approach roads		33,155	39,750	0.83	
Parking		27,600	31,690	0.87	

order to forecast the economic feasibility of public transportation developments.

4.5. Applying different scenarios

The proposed strategies, mentioned above, may be an effective tool in order to relieve the existing ATC for a certain area, but the individual application of any of them may not achieve any success. For example, in case of parking situation limited the overall ATC, the increase in roads' capacity using a co-ordinated traffic signals system has not any effect on the ATC. Furthermore, in the same case, if we chose a parking restriction policy to be applied, the city center parking situation will be improved but the ATC may be improved and may be not, as, if the traffic situation is good compared to parking situation, the effectiveness of parking situation on ATC will be good, but if the traffic situation is close to parking situation, the effectiveness of parking restriction will not have the pleasant effect on ATC. In such cases, two or more strategies should be applied.

Thus, in order to achieve the maximum benefits from the proposed strategies, a set of scenarios of traffic management strategies and travel demand management hypotheses should be formulated and evaluated to accomplish the best scenario which achieves the maximum ATC within a certain area. The co-ordinated traffic signals increased the traffic supply, while the travel demand management hypotheses decreased parking and traffic demand. In order to gain a maximum ATC which is compatible with a good level of service, the co-ordinated traffic signals were studied with each travel demand management hypothesis.

5. Alexandria city center as a case study

The planning process described above is applied to determine, roughly, the traffic capacity of Alexandria city center, and to

Figure 7 Suggested signals sites.

Table 4 Area traffic capacity after introduction of co-ordinated traffic signals.

Element	Car share (S_c)	Supply	Demand	Supply/demand	ATC (pcu/h)	Degree of saturation
Internal roads	17.9%	34,241	30,481	1.12	26,500	0.80
Approach roads		40,740	39,750	1.02		0.78
Parking		27,600	31,690	0.87		1.15

estimate the impacts of applying some traffic management strategies and travel demand management hypotheses in order to alleviate the current capacity restrictions. The current transport system in Alexandria city center is unsustainable and inadequate to suit the transport needs with a proper service quality. It can be described by its improper modal mix, un-integrated street networks, insufficient transport capacities for both private and public transport systems, lack of traffic management, and poor traffic safety. The study area of Alexandria city center covers approximately 4.0 km^2 (Fig. 5). A cordon line is defined around the central area, which almost goes with its boundary line. The cordon line cuts across all the approach roads leading to the city center.

5.1. Input data

5.1.1. Urban structure data

The network physical details were derived from a surveying map, satellite images, and site visit. The network is defined by links (roads) and by intersections. The study area of Alexandria city center covers approximately 4.0 km^2. Since traffic volume is the most basic parameter, the observation and analysis of the traffic volumes were done using video recording technique. The control types at intersections are collected. A public transportation survey process was conducted to collect data about the tram routes, the vehicles, the average speeds, the stops, the dwell times and the management at intersections.

5.1.2. Urban mobility data

The existing Alexandria city center population is determined as 319,130 inhabitants according to 1996 and 2006 census by using the linear trend method [16]. The existing Alexandria city center car ownership is estimated as 90 car/1000 people from the IDSC information reports (The Egyptian Cabinet – Information & Decision Support Center) [17]. The total peak hour generated and attracted trips are determined as 21,166 and 51,763 trip/h respectively, while the total existing peak hour internal trips are 10,335 trip/h, where the total existing peak hour through trips are 42,229 trip/h [11]. On the daily basis, work trips account for about 25% of total daily trips while it accounts for about 60% of total trips during peak periods [11]. Table 1 shows the distribution of trips according to their mode of transportation during normal weekdays for both work and all trip purposes [11].

The parking distribution for different trip purposes is determined through conducting a parking survey in order to observe the vehicles' proportion in a certain time for each parking purpose (residents, work or other). This type of data

Table 5 Traffic and parking situations after applying long-term parking restriction.

Element	Desired volumes for work trips (pcu/h)	Actual volumes for work trips (pcu/h)	Actual car share for work (%)	Desired car share for work trips (%)	Controlled car share for work trips (%)	Volumes after restraint for work trips (pcu/h)	Volumes after restraint for all trips (pcu/h)	Car Share for All trips (S_c) (%)	Supply	Supply/ demand	ATC (pcu/h)	Degree of saturation
Internal network	22,215	23,348	26.75	24.67	17.39	18,283	25,500	12.3	29,348	1.15	25,500	0.78
Approach roads	23,847	30,442		17.39		23,847	33,155		33,155	1		0.80
Parking	16,103	20,193		21.30		13,126	24,623		27,600	1.17		0.89

Table 6 Traffic and parking situations after applying public transportation improvements.

Element	Desired volumes for all trips (pcu/h)	Actual volumes for all trips (pcu/h)	Actual car share (%)	Desired car share (%)	Controlled car share for %	Volumes after shifting (pcu/h)	Supply	Supply/ demand	ATC (pcu/h)	Degree of saturation
Internal network	29,348	30,481	17.9	16.22	10.32	25,500	29,348	1.15	25,500	0.78
Approach roads	33,155	39,750		10.32		33,155	33,155	1		0.80
Parking	27,600	31,690		15.60		18,265	27,600	1.5		0.66

Table 7 Applying parking restrictions for work trips (according to parking situation only).

Element	Desired volumes for work trips (pcu/h)	Actual volumes for work trips (pcu/h)	Actual car share for work (%)	Desired car share for work trips (%)	Controlled car share for work trips (%)	Volumes after restraint for work trips (pcu/h)	Volumes after restraint for all trips (pcu/h)
Internal network	22,215	23,348	26.75	–	21.30	20,395	27,528
Approach roads	23,847	30,442		–		26,601	35,909
Parking	16,103	20,193		21.30		16,080	27,577

Table 8 Traffic and parking situations after second step of integration process.

Element	Desired volumes for all trips (pcu/h)	Actual volumes for all trips (pcu/h)	Actual car share (%)	Desired car share (%)	Controlled car share for %	Volumes after shifting (pcu/h)	Supply	Supply/demand	ATC (pcu/h)	Degree of saturation
Internal network	29,348	27,528	14.63	15.30	9.40	25,500	29,348	1.15	25,500	0.78
Approach roads	33,155	35,909		9.40		33,155	33,155	1		0.80
Parking	27,600	27,577		14.63		17,731	27,600	1.56		0.64

may be collected by a vehicle plate registration process, such as parking survey process. The vehicle plate registration process was carried out by video recordings for random samples from on-street parking within the study area. The peak hour parking coefficients for the various trip purposes (residents, work and others) were determined to be: $m_r = 0.29$; $m_w = 0.69$; and $m_o = 0.094$.

5.1.3. Calibration data

Average link speed as well as average link travel time are collected from the field as a measure of effectiveness in order to compare it with the VISSIM output. At some intersections observers were placed to record the queue length of major approaches. At intersections observers were instructed to record the queue length at the start of the green interval and the end of the yellow interval. This study was conducted during specific periods of study. Alexandria central area contains a number of parking places, whether on street parking or off-street parking. There are six main parking places (off-street) serving the number of travelers to the city center area, in addition to many on-street parking. The parking capacity in Alexandria city center was found to be 27,600 parking places.

5.2. Existing ATC calculation

Using Eq. (1); the peak-hour traffic volumes on internal road network (V) for Alexandria city center are estimated to be 30,481 pcu/h distributed as follows:

- V_e = external/internal + internal/external traffic volumes during peak hour = 15,191 pcu/h;
- V_t = through traffic volumes during peak hour = 12,280 pcu/h; and
- V_i = internal traffic volumes during peak hour = 3010 pcu/h.

On the other hand, by using Eq. (2), the peak-hour traffic volumes on the approach roads (V_a) are found to be 39,750 pcu/h.

The Alexandria city center VISSIM model is used to estimate the existing road network capacity (internal roads and approach roads). Traffic volumes, speeds, public transport data were defined where the first run is taken place. A typical VISSIM run of the existing conditions model used for this study took an average of about 20–30 min to simulate a one simulation hour.

As in any other simulation model, VISSIM contains a number of parameters that represent the driving behavior characteristics in the country where the model is originally introduced and calibrated. Therefore, the successful utilization of any traffic simulation model depends on selecting the proper values of the parameters that describe the driver performance characteristics in the area where the model is to be used. Table 2 represents the VISSIM parameters [15] which used to conclude the calibrated model and validated in validation model. After simulating the network with VISSIM default values, it was found that the most of the performance measures do not match the observed data (Fig. 6a). Therefore, a set of parameter values for calibration were considered and network is simulated using these parameter values. Table 2 shows the best set calibration parameters which give a comparison within the validation criteria thresholds (Fig. 6b).

After calibrating the model, the validity of these calibrated values is checked by applying them on the same network during other peak period. Field observed data were compared with the corresponding data of the simulated results and is found to be satisfactory. Hence it could be said that with these calibrated values VISSIM simulation model is fully suitable for the current traffic conditions of Alexandria city center. Based on the calibrated/validated model, the existing capacity of Alexandria city center internal road network is estimated to be32608 pcu/h, while the total capacity of all approach roads leading to this network according to its conditions is found to be 41,443 pcu/h.

Using Eq. (4), the daily car traffic volumes for both work and other purpose trips were estimated:

$\mathrm{DVT}_{c,w}$ = daily traffic volume by car for work trips = 28,846 cars/day.
$\mathrm{DVT}_{c,o}$ = daily traffic volume by car for other purpose trips = 32243 cars/day.

According to the socio-economic data and the peak hour parking coefficients, the peak hour parking demand is estimated using Eq. (3) and found to be 31,690 parking places. Night demand (residents parking) is also estimated using $m_r = 1.0$ and found to be equal to 27,577 parking places. On the other hand and based on the field survey, the parking capacity in Alexandria city center was found to be 27,600 parking places.

In order to determine the existing traffic supply for the internal road network and approach roads, the designed level of service for both of them should be considered. More desirable conditions are resulted when the roads of the central area are operated at service level D ($0.8 < \mathrm{LOS} < 0.9$). This would be the border case situation which could still be tolerated by the car users [52]. Thus, the traffic volumes in the central area internal roads should be restricted and reduced to be 29,348 pcu/h (desired traffic volumes of the city center internal roads). Thus, the traffic supply of internal road network is equal to 29,348 pcu/h where the traffic demand is equal to 30,4810 pcu/h.

For approach roads leading to the city center, it is generally recommended that the main road corridors of an urban area are operated at level of service C ($0.6 < \mathrm{LOS} < 0.8$) [52]. Hence, the traffic flow on the approach roads leading to the city center of Alexandria should not exceed 33,155 pcu/h (desired traffic volumes of the city center approach roads). Thus, the traffic supply of approach roads is equal to 33,155 pcu/h where the traffic demand is equal to 39,750 pcu/h. The traffic and parking situations (supply/demand ratios) define the overall central area traffic capacity – ATC (Table 3). This means that the area traffic capacity can be determined by multiplying the lowest value of the different supply/demand ratios (0.96, 0.83 and 0.87) by the actual unrestrained internal traffic volumes (Eq. (5)). As a result, Alexandria Central area traffic capacity = $0.83 * 30{,}481 = 25{,}500$ pcu/h. This ATC value shows that, there are problems in Alexandria city center represented in the highly traffic volumes of the existing roads' infrastructure which produce severe congestion, as well as the parking shortages. The existing ATC is less than the traffic demand for both internal and approach roads. Therefore, in order to relieve ATC, four alternatives are introduced as proposed policies; applying coordinated traffic signals as one

Table 9 The effect of applying the proposed scenarios on alexandria city center ATC.

Scenario no.	Description	S_c (%)	ATC (pcu/h)	Traffic and parking situations		
				Internal roads	Approach roads	Parking
				Level of service		Degree of saturation
				Accep. ⩽0.9	Accep. ⩽0.8	Accep. ⩽1
1	Do-nothing	17.90	25,500	0.93	0.95	1.15
2	Co-ordinated traffic signals	17.90	26,500	0.80	0.78	1.15
3	Long-term parking restrictions	12.30	25,500	0.78	0.80	0.89
4	Public transportation improvements	10.32	25,500	0.78	0.80	0.66
5	Integration of parking restrictions and public transportation improvements	9.40	25,500	0.78	0.80	0.64
6	Scenario 2 + scenario 3 [changing car share]	14.63	27,500	0.72	0.71	1
7	Scenario 2 + scenario 3 [remaining car share]	12.3	28,600	0.67	0.65	0.89
8	Scenario 2 + scenario 4 [changing car share]	15.60	29,000	0.76	0.74	1
9	Scenario 2 + scenario 4 [remaining car share]	10.32	31,365	0.67	0.65	0.66
10	Scenario 5 + scenario 2 [remaining car share]	9.40	31,365	0.67	0.65	0.64

of traffic management policies, applying the parking restriction measurement as one of travel demand management policies, applying the public transportation development as one of travel demand management policies and the integration of parking restriction and public transportation development.

5.3. ATC improvement policies

5.3.1. Introduction of co-ordinated traffic signals

The first step for applying co-ordinated traffic signals is the selection of signals sites. The selection of signal sites depends on the intersections of overcrowded traffic, which causes traffic congestion for overall city center according to site investigation process that is carried out at the same time of data collection. Fig. 7 shows the selected intersections which need the application of traffic signal programs.

After selection of signals sites, the offsets and phase times should be designed according to the existing maximum traffic volumes at each intersection. In order to gain powerful co-ordinated traffic signals, the offsets and phase times for the proposed corridors should be optimized by the help of the micro-simulation model which is developed, calibrated and validated before. In order to optimize these times, the designed traffic signals were coded and ran by VISSIM on a common phase and offset time for each corridor. Thus trials to increase the roads capacity happened by modifying the signals' timing for some intersections. These trials were continued until the roads capacity increased to maximum extent. The micro-simulation modeling VISSIM obtained that the total capacity of the internal road network for Alexandria central area after the application of the proposed co-ordinated traffic signals increased to be 38,045 pcu/h (instead of 32,608 pcu/hr) and the total capacity of all approach roads leading to this network increased to be 50,924 pcu/h (instead of 41,443 pcu/h). Table 4 clearly shows that despite the increase in approach roads and internal roads, the increase in ATC is not effective as desired. This refers to the fact that the existing ATC resulted from the insufficient parking capacity. This indicates that the ATC depends, also, on area parking capacity where the parking situation is so close from traffic situation, hence, the proposed co-ordinated traffic signals are useless without increasing parking capacity or decreasing the parking demand by using one or two of the Travel Demand Management (TDM) hypotheses.

5.3.2. Long term parking restriction hypothesis

Long term parking restrictions limit the private car share of work trips to the city center. The net capacity available for work trips has to be determined by subtracting the demand created by other traffic from the total capacity. Then, the desired car share of work trips can be determined according to Eq. (6) (V_w = 23,348 pcu/h and $V_{a,w}$ = 30,442 pcu/h). Table 5 presents the effect of parking and traffic situations on car share of work trips to the central area after applying parking restriction for work trips.

5.3.3. Public transportation improvement hypothesis

Improvement of public transport service leads to reducing the usage of private car. All trip purpose will be affected considering that. Only bus modes (B) will load by the overload travels. Table 6 presents the effect of parking and traffic situations on car share to the central area after applying public transportation improvements.

5.3.4. Integration of parking restriction and public transportation improvements

The integration process was applied through two steps. The first is applying parking restrictions to determine the desired car share for work trips which achieves a balance between parking demand and supply regardless of the traffic situation. The second is applying public transportation improvements to determine the final desired car share which achieves a balance between the traffic supply and the traffic demand.

Table 7 presents the first step of integration process where the desired car share for work trips was determined according to the parking situation only without depending on the traffic situation. The desired car share for work trips was calculated to be 21.3%. Thus, the traffic volumes which are produced by the desired car share were determined. The desired car share for all trip purposes was determined according to Eq. (7) and founded to be 14.36%.

Table 8 shows the second step for integration process where the car share was considered to be 14.36% and the desired car share was determined according to traffic situation (traffic supply and traffic demand form first step). The table also presents the traffic and parking situation after the integration process, as well as the ATC. It, also, shows that the ATC has not changed while the roads' levels of service were increasing. The desired car share was determined to be 9.40% while the desired share for bus modes was determined to be 11.9% instead 6.40%. Thus, the improvement process in the bus facilities will be according to the difference between the current and the desired bus ratios.

5.3.5. Applying different scenarios

In order to maximize the current ATC to alleviate traffic and parking congestions and improve the levels of service of Alexandria city center road network, the co-ordinated traffic signals should be applied side by side with one of travel demand management hypotheses. The co-ordinated traffic signals increased the traffic supply while the travel demand management hypotheses decreased parking and traffic demand. In order to gain a maximum ATC which is compatible with a good level of service, the co-ordinated traffic signals was considered with each travel demand management hypothesis. There are two proposed methods to combine between the co-ordinated traffic signals and any travel demand management hypothesis. The first is using co-ordinated traffic signals to increase roads' capacity; thus concluding the required desired car share according to the new roads' capacity and the proposed TDM hypothesis. The second method is using TDM hypothesis to conclude the desired car share according to the current roads' capacity; thus using co-ordinated traffic signals to increase roads' capacity. Table 9 summarizes the effects of applying the available scenarios on Alexandria city center ATC, desired car share, levels of service of approach roads and internal road network, and the degree of saturation of parking places within the area.

6. Conclusion

The main objective of this paper is to present a planning process which can be used as a tool to determine the current ATC within a city center area, as well as evaluating different strategic solutions (or scenarios). Each of them includes different possible improving strategies such as traffic management strategies and travel demand management hypotheses. Area Traffic Capacity (ATC) for a central area is an expression that can be defined as the maximum number of vehicles that can, at a given time, move or park in the area. It could be either the capacity of the internal road network, the parking capacity, or the capacity of the approach roads leading into the area.

The proposed planning process is applied to determine the traffic capacity of Alexandria city center as case study, and to estimate the impacts of applying some traffic management strategies and travel demand management hypotheses in order to alleviate the current capacity restrictions. The process appears to be a useful tool for analyzing the traffic and parking situations under different planning hypotheses, and for assessing an effective and a sufficient traffic system in the city center.

There are four additional features seem to be very interesting in the proposed planning process:

(a) The estimation of the parking demand and the traffic volumes on an area road network from O–D person trip matrices.
(b) The usage of the micro-simulation modeling to estimate roads' capacity under the current traffic control conditions, as well as, under a proposed traffic management system.
(c) The usage of the supply/demand ratios to evaluate the traffic situations in the city center and to develop a balanced solution in which both roads and car parks are saturated to the same extent.
(d) The effect of applying number of traffic and parking policies on traffic and parking situation either in the case of increasing capacity or in case of achieving shift in modal spilt from private car to public transportation.

The need for such a planning process has recently increased. So far, there are no tools available for estimating the parking supply in the central areas which goes with the parking demand and at the same time with the internal road network capacity. Furthermore, it is still difficult to predict the likely effect of traffic and parking restrictions (as well as some other policies) on the travel behavior, and consequently on the level of service in the central areas.

Further research works in this scope should concentrate on investigating the modal split feedback effects on the operation of the different transportation systems of the urban area.

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